Intro to Biogeochemical Modeling in CESM/POP

Mathew Maltrud, LANL

Based on a presentation generously made available by Keith Lindsay, NCAR

Outline

1) What do we mean by "biogeochemistry"
2) Techniques for Modeling Biological Productivity
3) Some examples

What is Ocean BGC?

1) Chemistry of CO_2 (Dissolved Inorganic Carbon, DIC)
    1) Balance of acids, bases
    2) pH
        1) current global surface average = 8.07
        2) Effects on ocean-atmosphere exchange (ocean C sink)
        3) Effects on marine life
            1) Corals
            2) Plankton with $CaCO_3$ shells

What is Ocean BGC?

1) Ocean Ecology/Ecodynamics
    1) Global food web
    2) Affected by pH
    3) Distributions of phytoplankton, zooplankton, bacteria, higher level consumers
    4) Distributions of nutrients (N, P, Si, Ca, O, Fe, Cu…)
    5) Distributions of Dissolved Organic Matter (DOM) and Particulate Organic Matter (POM)
        1) "Biological pump" of C from the atmosphere to ocean depths

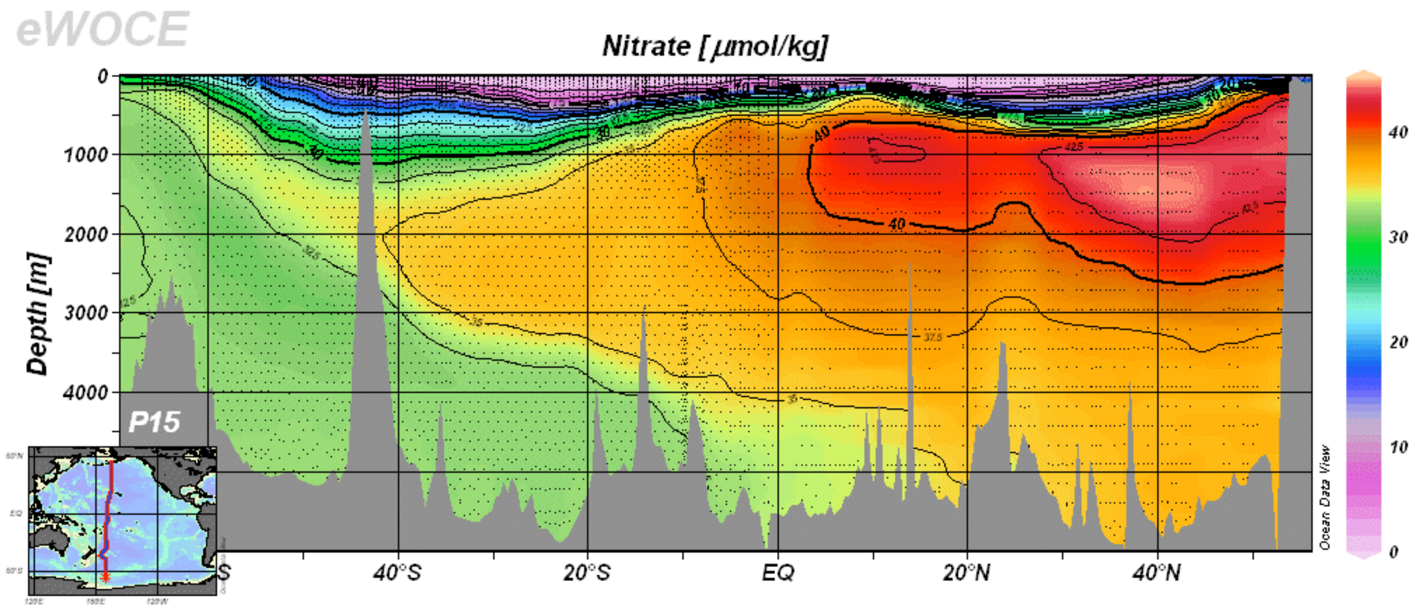
What is Ocean BGC?

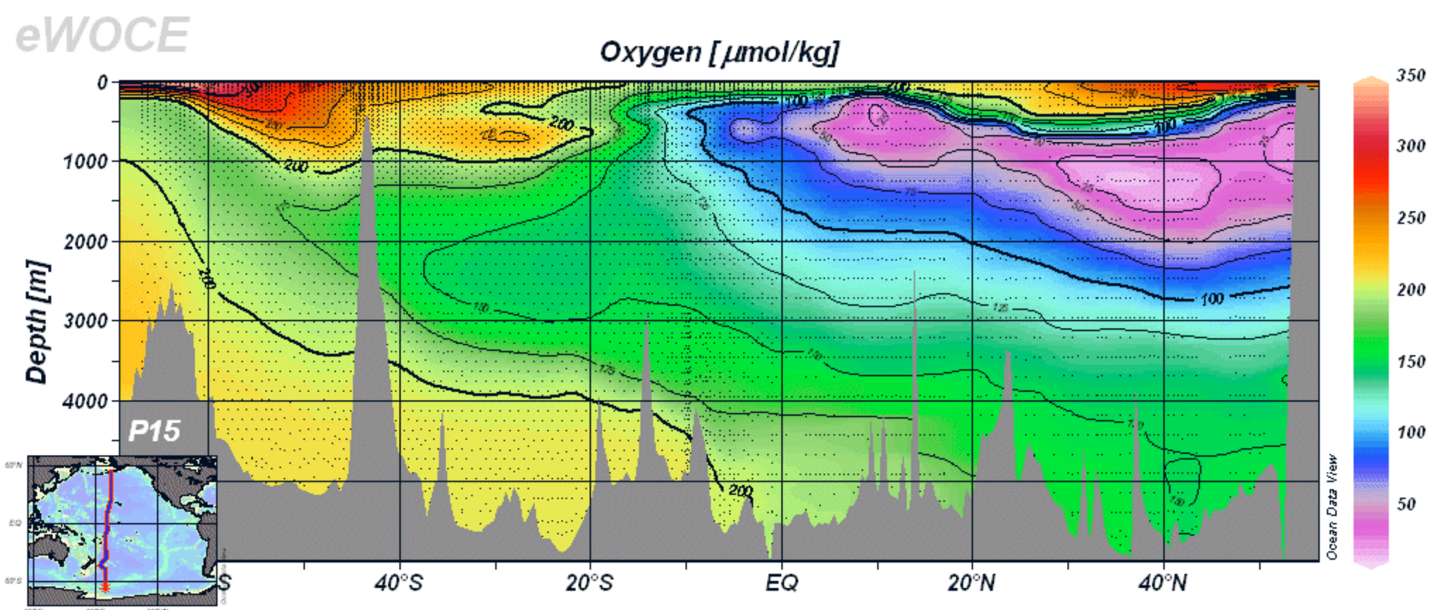
1) Atmosphere/Climate Feedbacks
    1) Strongly coupled to ecodynamics
    2) Radiation (direct)
        1) CO_2
        2) CH_4 (much stronger greenhouse gas per molecule)
    3) Clouds (indirect)
        1) Dimethyl sulfide (DMS) provides condensation nuclei
    4) Large number of atm chem reactions
        1) CO, NO_x => O_3
    5) Dust
        1) Major supplier of Fe to the surface ocean

What is Ocean BGC?

1) Anthropogenic Compounds
    1) Industrial
        1) Chlorofluorocarbons (CFCs)
    2) Radioactive
        1) H3 from bomb testing
        2) I-129 from reprocessing
    3) Typically used for model validation

NO_3 (a nutrient), O_2 (dissolved gas) Along Pacific Transect





Primary Processes Governing Distribution of Nutrients, O_2, Carbon, etc.

- Biological Productivity in Euphotic Zone
  - Consumes Nutrients & Inorganic Carbon
  - Produces Organic Matter & O_2
- Export of Organic Matter out of Euphotic Zone
  - Sinking Particles (e.g. detritus, $CaCO_3$ shells, …)
  - Circulation of Suspended Matter
- Remineralization of Organic Matter
  - 'reverse' of productivity, consumes O_2
- General Circulation
  - Advective Transport
  - Lateral & Vertical Mixing
- Temperature Dependent Air-Sea Gas Exchange

So the challenge is in how to model this complex set of interactions within the framework of an Ocean General Circulation Model

Fundamental Modeling Premise

Treat BGC quantities as “passive” tracers defined by their concentration (eg, mmol/m3) whose evolution is described by a set of coupled ODEs

An example of the simplest version of this type of model "NPZD"

N Nutrient
  nitrate, ammonium,
  phosphate, silicate, iron, etc.

P Phytoplankton
  photosynthesizers

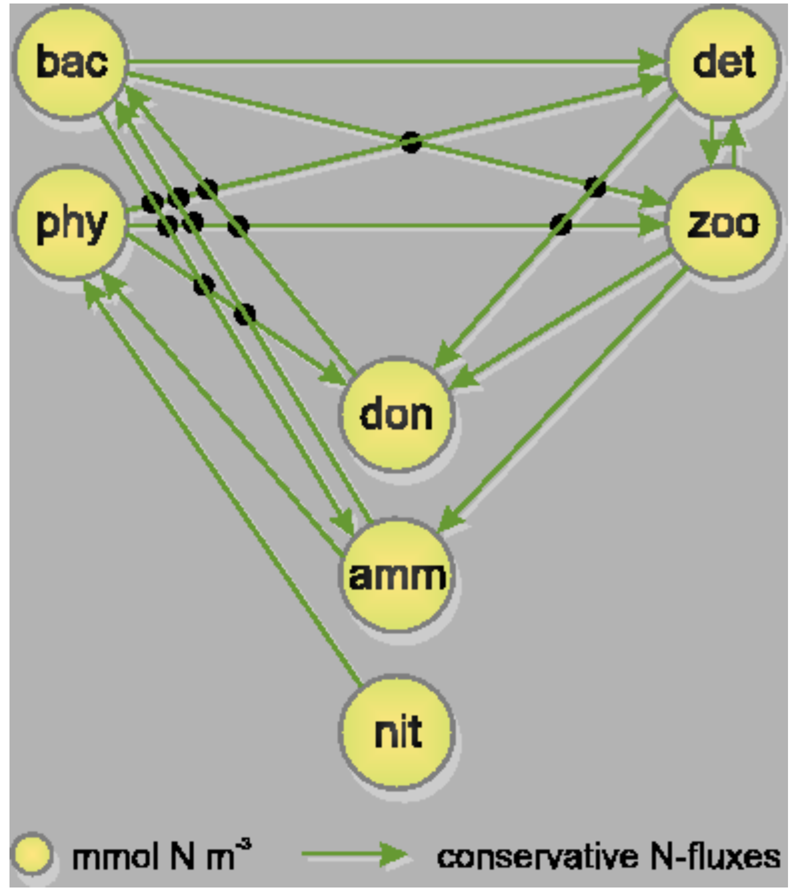
Z Zooplankton
  grazers

D Detritus

<u>Canonical Example</u>

Fasham, Ducklow, McKelvie, Journal of Marine Research, Vol. 48, pp. 591-639, 1990.

Many more variations are used…



Fasham model diagram from www.gotm.net

Simple NPZ Model

$$\frac{dP}{dt} = \mu_0\left(\frac{N}{k_N + N}\right)\left(1 - e^{\alpha E/\mu 0}\right)P - g\left(\frac{P}{k_P + P}\right)Z - m_P P$$

Nutrient limitation | Light limitation | Grazing | Mortality

$$\frac{dZ}{dt} = ag\left(\frac{P}{k_P + P}\right)Z - m_Z Z$$

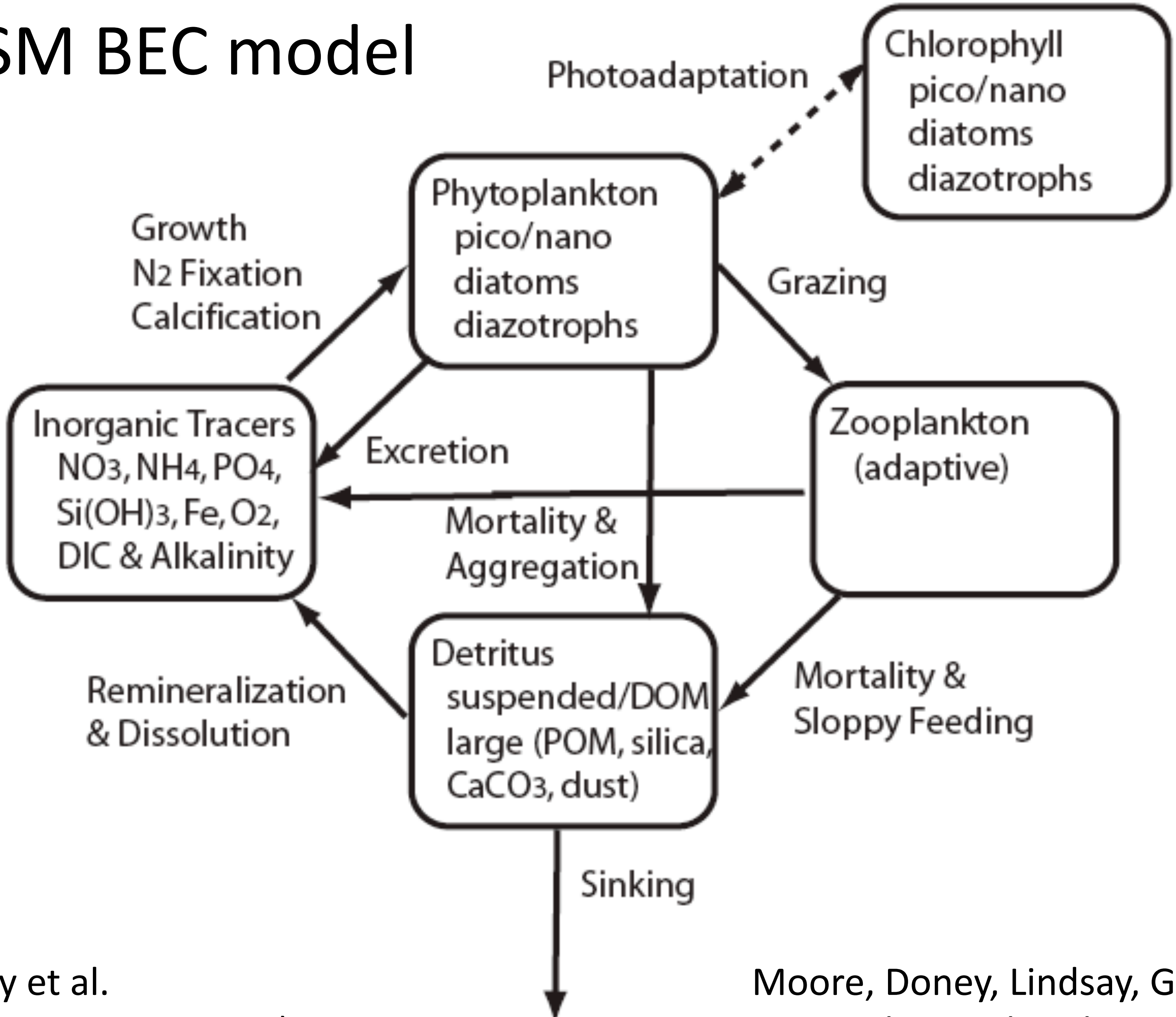
$$\frac{dN}{dt} = -\mu_0\left(\frac{N}{k_N + N}\right)\left(1 - e^{\alpha E/\mu 0}\right)P + (1-a)g\left(\frac{P}{k_P + P}\right)Z + m_P P + m_Z Z$$

- Three coupled ordinary differential equations
- Mass conservation

Plankton Functional Types (PFTs)

- Categorize plankton species by how they function and use representative types/groups
- Example definition from Le Quéré et al., Global Change Biology, Vol. 11, pp. 2016-2040, 2005.
  - Explicit biogeochemical role
  - Biomass and productivity controlled by distinct physiological, environmental, or nutrient requirements
  - Behavior has distinct effect on other PFTs
  - Quantitative importance in some region of the ocean

CCSM BEC model



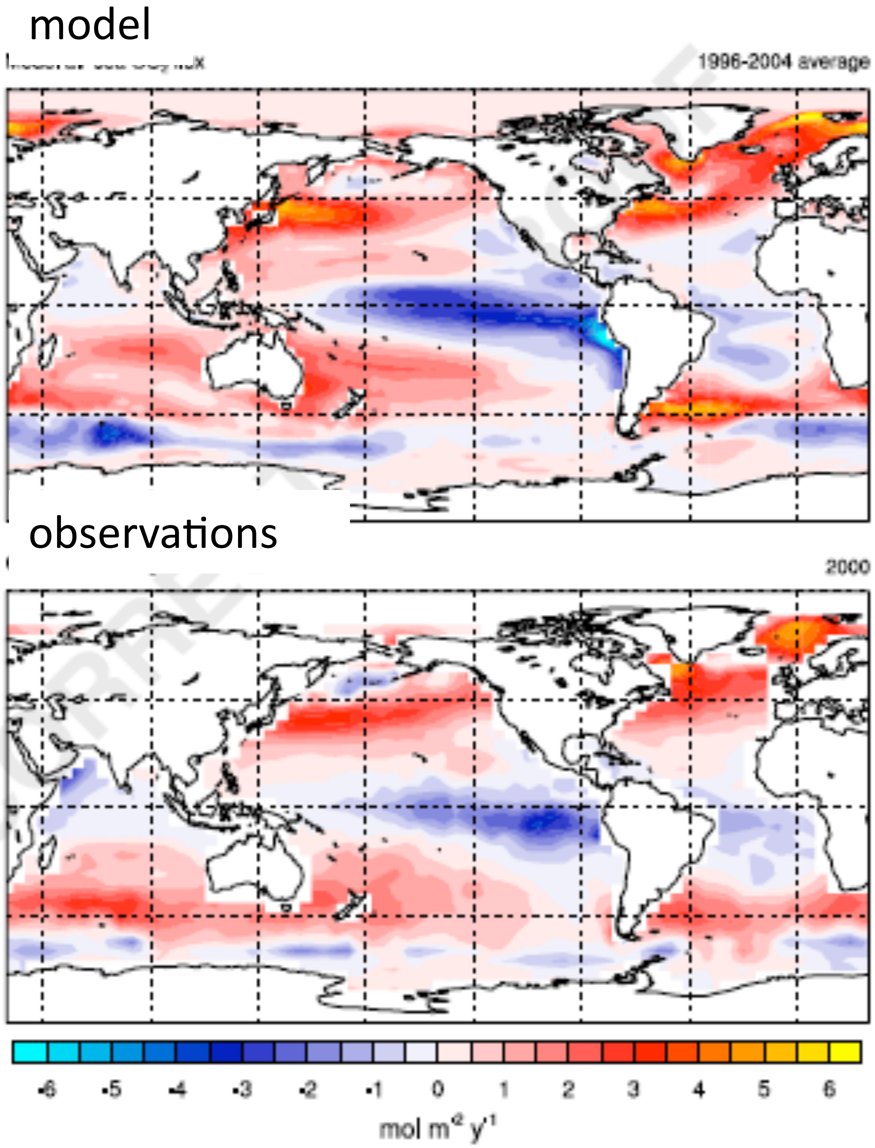
Doney et al.
(J. Mar. Systems, 2009)

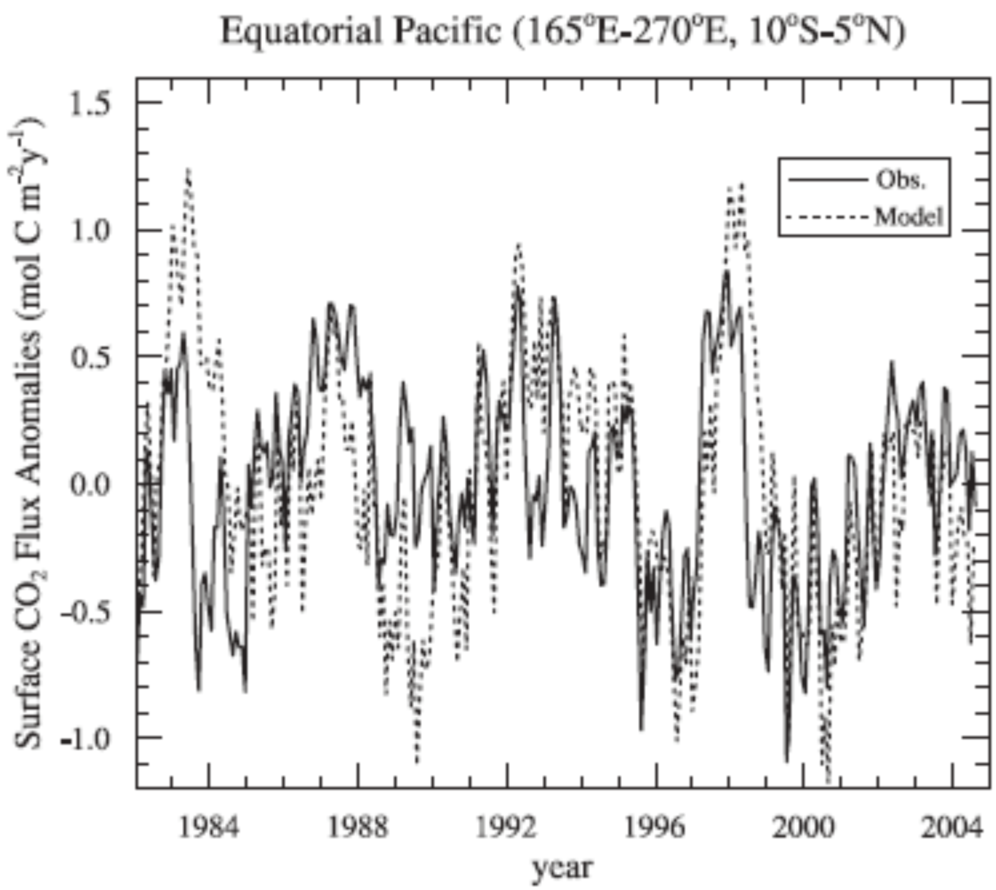
Moore, Doney, Lindsay, Global
Biogeochemical Cycles, 2004.

Model Validation
Examples of Data Sets

- Macronutrients (PO_4, NO_3, SiO_3) and O_2 from World Ocean Atlas
- DIC, ALK from GLODAP Analysis
- pCO_2 and CO_2 Flux assembled by Takahashi
- Surface Chl measured by satellite
- Productivity estimated from satellite
- JGOFS study sites
- HOTS & BATS timeseries

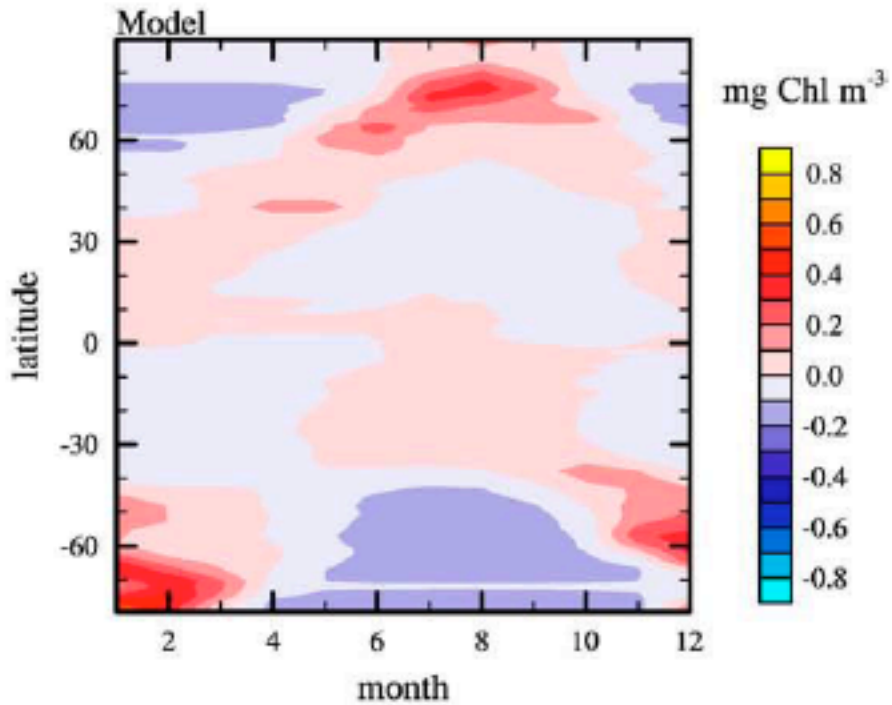
Air-sea CO_2 Flux

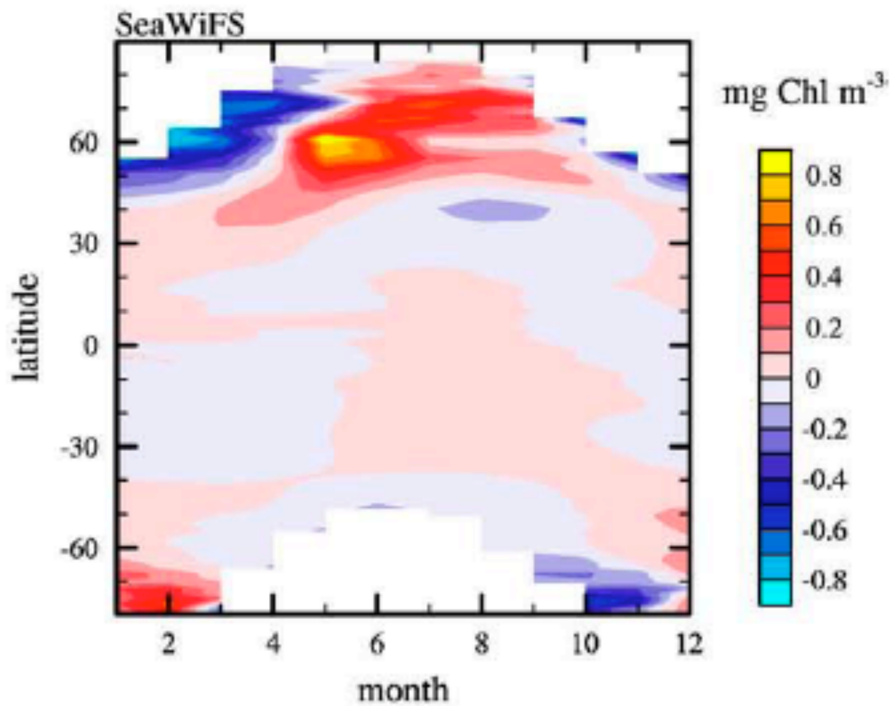


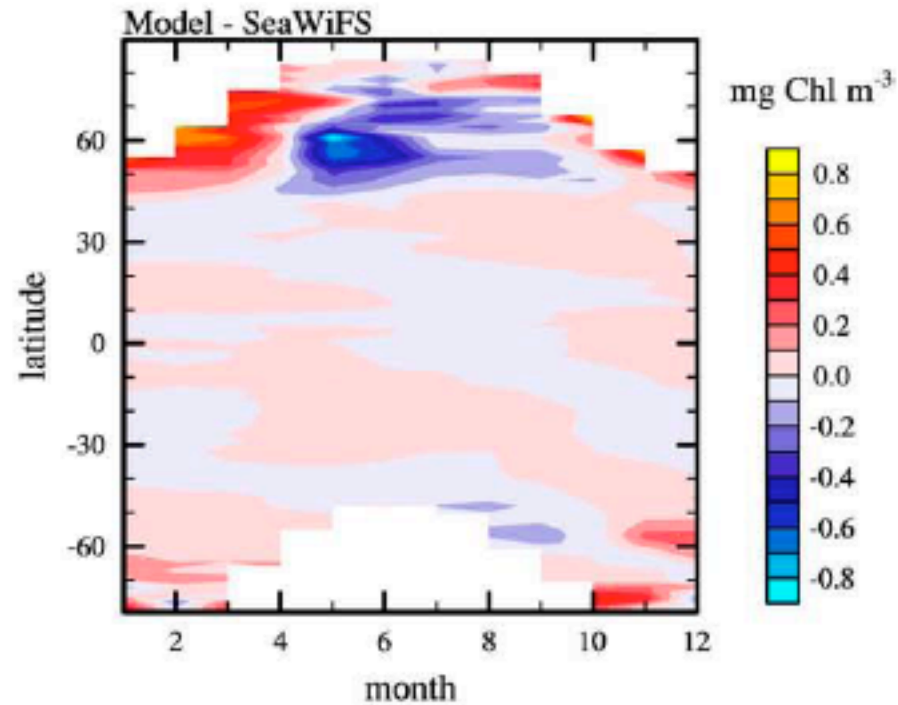


Doney et al. (Deep-Sea Res. II, 2009)

Satellite Ocean Color Comparison







Known Challenges

- Optimize BGC model parameters
  - Functional group approach increases uncertainty of parameters (i.e. multiple species, with different characteristics, are clumped together)
  - Don't want to overtune too much to compensate for biases in physical model
- Given BGC model parameters and physical circulation, generate balanced BGC state
  - Need to deal w/ diurnal to millenial timescales
  - Using Newton-Krylov for this is a work in progress